Transonic Dynamic Stability Instigations of a 45 **degree** Were-f:onc **with Hemispherical Afterbody**

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Extended Abstract:
The subject of planetary entry using blunt bodies has beco studied extensively in the past. One aspect of the aerodynamics of this type of vehicle that has not been addressed at length is their transonic dynamic stability characteristics. In the past, measurements have bcco made in wind tunnels and ballistic ranges that indicate low angle-of-attack instabilities in tbc transonic flight regime of these blunt bodies that lead to angle-of-attack limit cycles that arc observed in tbc missions, These limit cycles can result in angle of attack envelope growths to as large as 15 degrees as the vehicle passes through supersonic into transonic flight. As onc might expect, it has also been observed that these instabilities arc dependent on the Reynolds number and to a lesser extent, the Strouhal number.

Planetary entry missions to date such as Gallileo, Piooccr Venus Orbiter, Viking, Apollo, Soyuz, etc. have not bcco extremely sensitive to this transonic motion growth; Therefore, past studies have not focused on limiting the problem. The Jet Propulsion Laboratory's New Millennium Mars Microprobe (MMP) is a Martian penetrator mission (scheduled for launch in January 1999, entry in December) that is very sensitive to these quantities. Additionally, the MMP is required to have a geometry such that only one trim point exists in the hypersonic flight regime, because the vehicle is in an uncontrolled attitude at atmospheric interface and needs to passively stabilize to the forward facing attitude in the upper atmosphere, 'his is also a unique requirement because many of the vehicles flown in the past were either spun or 3-axis stabilized to ensure the atmosphere was encountered at near zero angle-of-attack and therefore, they had no penalty for more than onc trim point.

This paper describes the development and testing of a blunt entry body with a high degree of transonic dynamic stability and onc hypersonic trim point. Because of the inadequacy of CFD techniques to predict dynamic characteristics of blunt vehicles in the transonic flight regime, a series of tests was performed Aerodynamic coefficient data from a high Reynolds number transonic ballistic range test, done at tbc Wright Patterson Armament Directorate's Aeroballistic Research Facility (ARF) is presented, as well as data from the Central Research Institute of Machine Building (TsNII Mash, located in Moscow, Russia) U-21 lo~v-density transonic wind tunnel. Eighteen ballistic range tests in the ARF were done in July 1996 to determine static and dynamic coefficients from $M=1.4$ to $M=0.8$ at $Re=1.5\times10^6$. Wind tunnel runs at TsNIIMash will be done (November 1996) at similar Mach numbers with Reynolds numbers of approximately 50,000, Comparison of the dynamic as well as static characteristics from the low and high Reynolds numbers will bc performed.

Three factors were incorporated into the aerodynamic design of the vehicle that increase the dynamic stability, They arc: 1) moving the C.G. as close to the front of the vehicle as possible, 2) using as "'sharp"

a vehicle as practical (i. e., minimum cone angle and minimum nose and corm radii), and 3) the addition of a hemispherical cap centered at the C.G. A C.G. near the nose of the vehicle clearly increases the static stability of the vehicle, and has been shown in earlier Viking ballistic range tests to improve the dynamic stability characteristics. The second factor helps to limit the relative size of the separation region behind the body as well as minimizes fluctuations in the position of both separations points and sonic line transitions caused by small angle-of-attack changes. The addition of a hemispherical cap centered at the C.G. ensures that pressure fluctuations resulting from the unsteady base flow will act through the center of gravity, causing no resultant moment on the vehicle. Additionally, viscous forces, albeit small, on the cap will tend to operate in the directions opposite rotation and damp motions. Although these three design parameters have been looked at independently in the past, this is the first vehicle to combine all three and maximize dynamic stability. Of course, tradeoffs need to be made to ensure the entry vehicle design can accommodate the penetrator payload and meet mission requirements. The dimensions of the ballist ic model tested arc shown in Figure 1a, with the diameter scaled to 1. Figure lb is a photograph of the model and sabot.

Figure 2 shows the limit cycle characteristics of the blunt Cassini Huygens probe, from ballistic range tests at the ARF. It shows a limit cycle of approximately 12 degrees, and is representative of the transonic dynamic stability characteristics of many blunt entry vehicles, Figure 3 represents data taken from the same facility for the MMP. Clearly, the dynamic instabilities have been greatly reduced; Preliminary analysis indicates the limit cycle is less than 2 degrees. The data from the ballistic range tests have been reduced to static and dynamic coefficients using non-linear reverse ballistic techniques with the ARFDAS code developed by ArrowTech in Burlington, VA. These techniques allow for investigation of Mach and angle-of-attack dependence of static and dynamic coefficients. Figures 4 through 7 show static and dynamic coefficients as a function of the Mach numbers studied, Preliminary results indicate little variation of C_{mq} with angle-of-attack, whereas traditional blunt body vehicles have a large unstable spike in C_{mq} near zero angle-of-attack, The coefficients are subsequently used to perform high fidelity six degree of freedom entry simulations of the full-scale vehicle with correct mass properties in a Martian atmosphere, although trajectory results arc not presented here.

Because the ARF is an atmospheric pressure facility and Mars has a low density atmosphere (-7 torr surafce pressure), the ballistic range tests had Reynolds numbers two orders of magnitude higher than the predicted flight conditions. Boundary layer, wake structure, and the nature of the flow separation were not simulated well and certainly these factors contribute to dynamic stability characteristics. How'ever, few operational facilities exist that can provide low Reynolds number dynamic stability tests at transonic speeds. The U-2 1 variable density transonic wind tunnel at the Central Research Institute of Machine Building is currently preparing models for both a free oscillation dynamic test and static force balance test. This test will provide a much more realistic simulation of the terminal aerodynamics of the entry trajectory. A limited amount of data from Viking and the Russian Mars '96 mission indicates increasing dynamic stability with decreasing Reynolds number.

The final result of this work is the aerodynamic design for flight hardware scheduled to be delivered in July 1997.

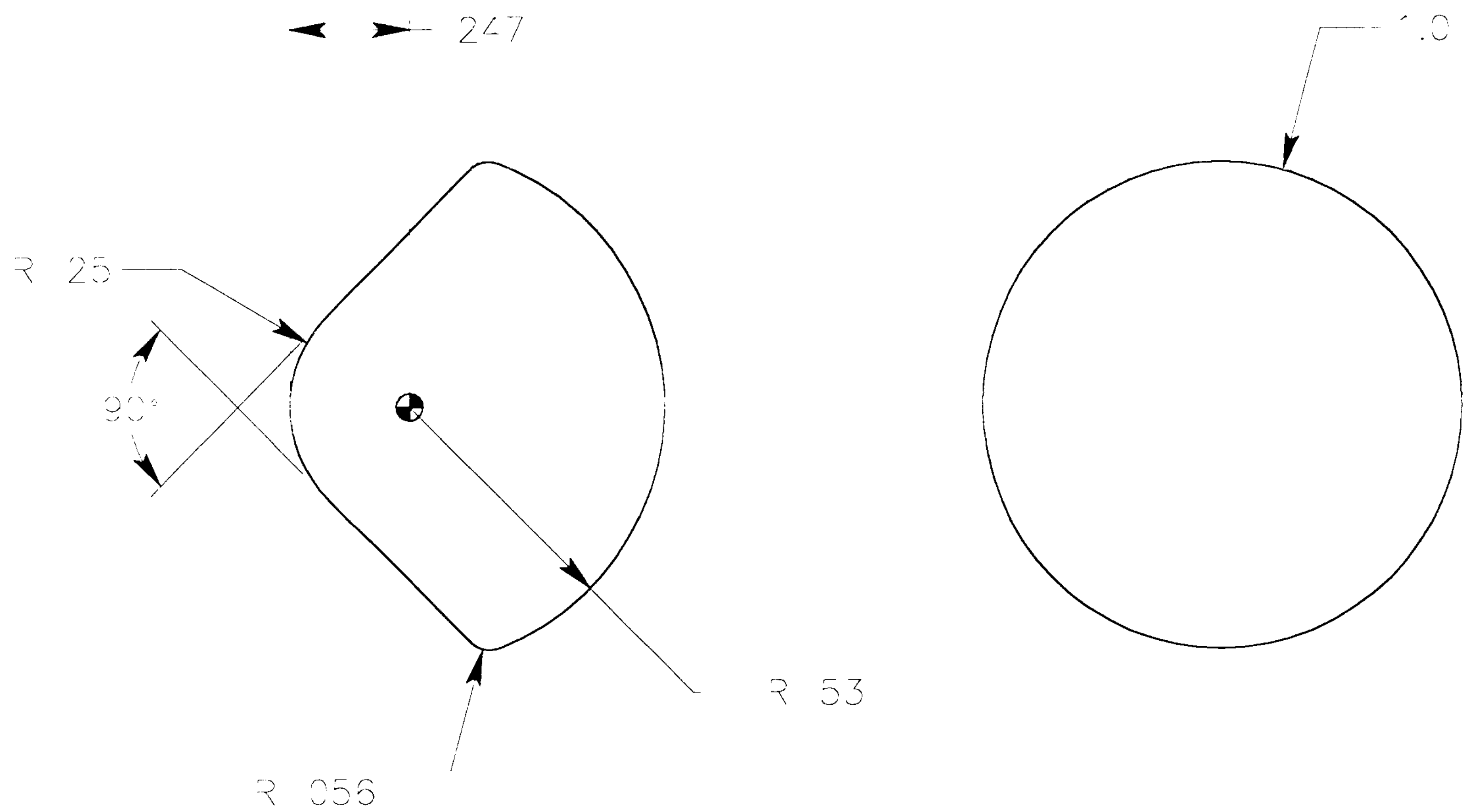


Figure 1a: Ballistic Mode Geometry

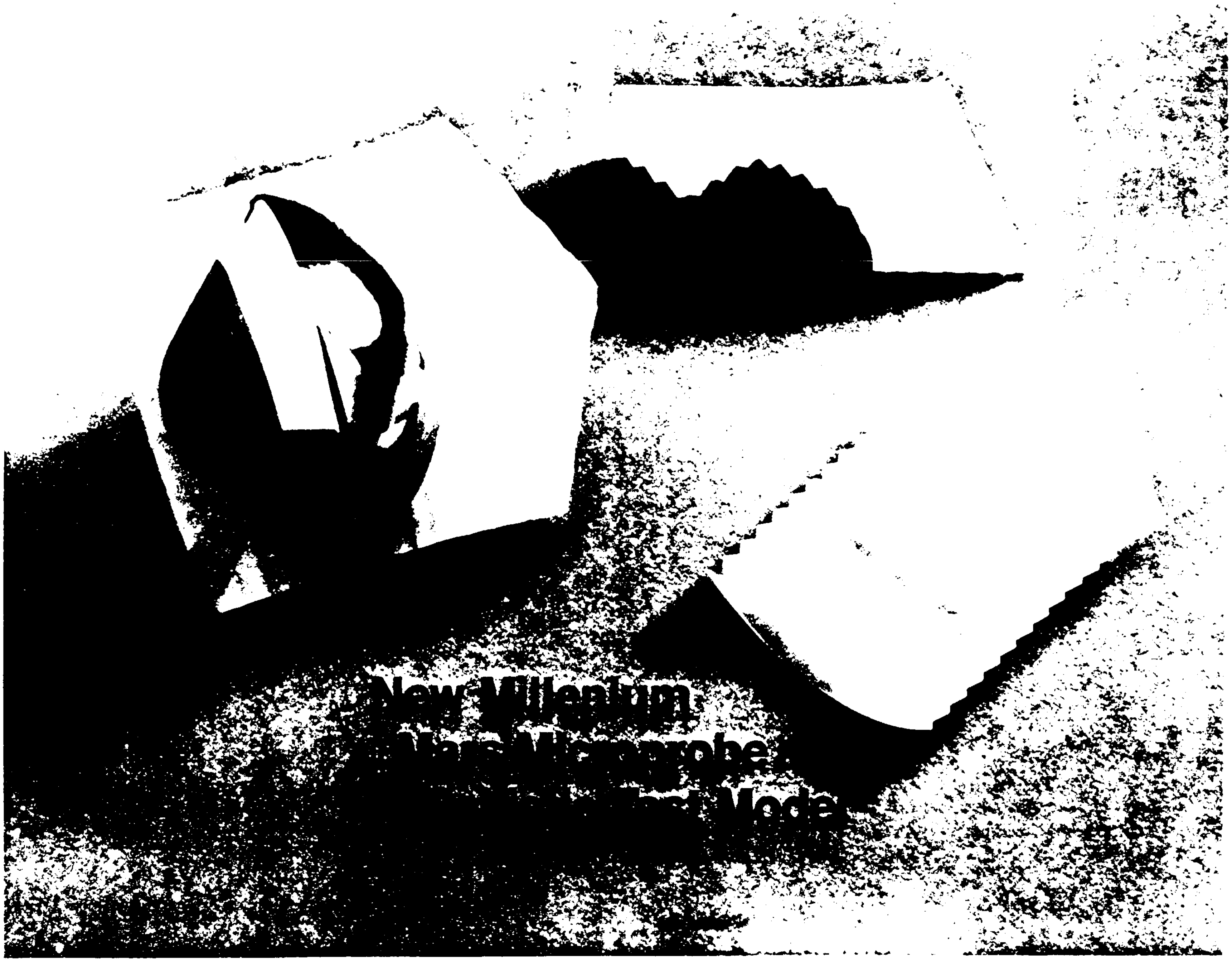
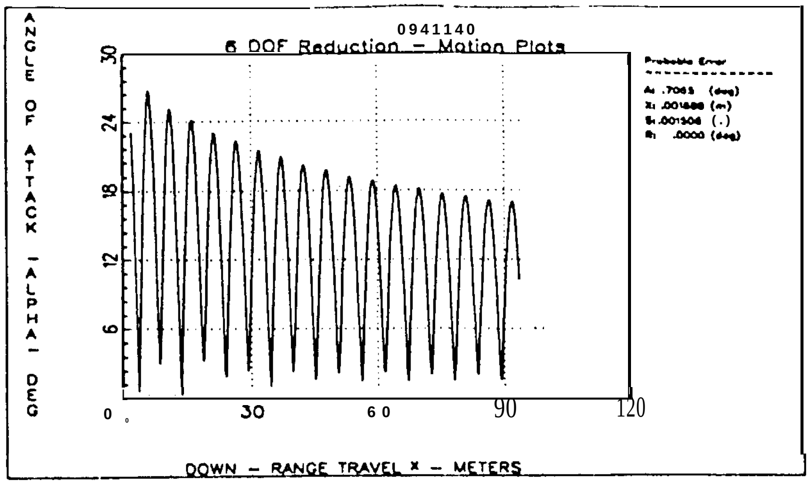
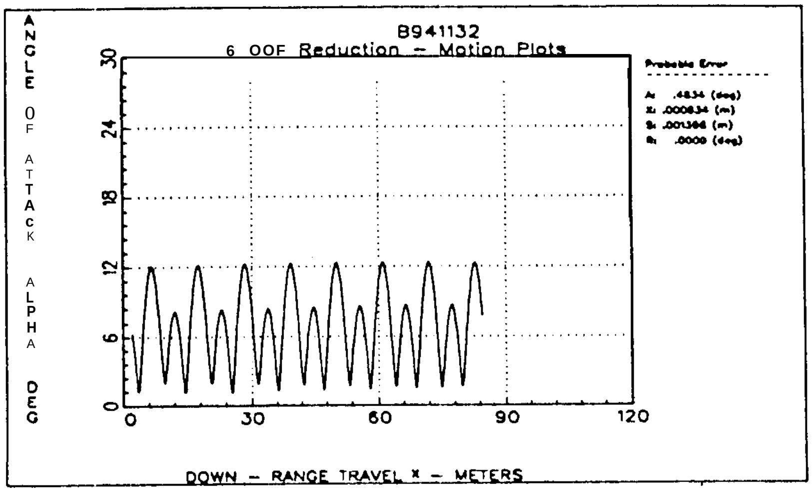
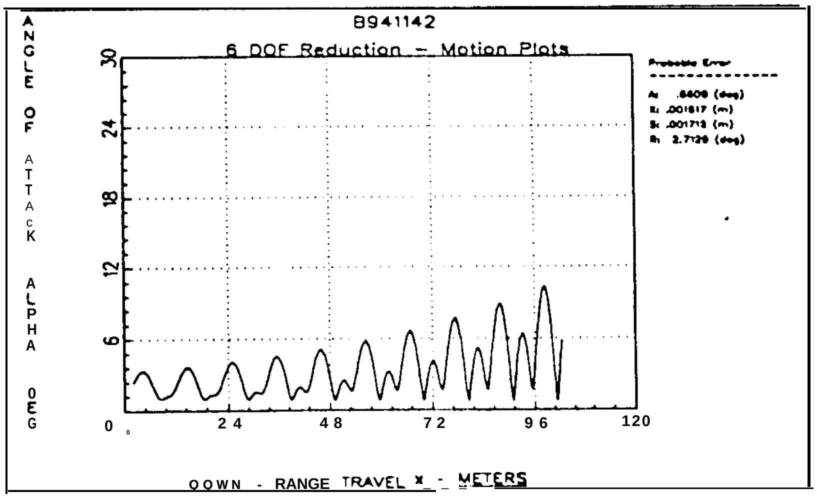


Figure b







Huygens Probe Transonic Limit Cycle

Figure 2

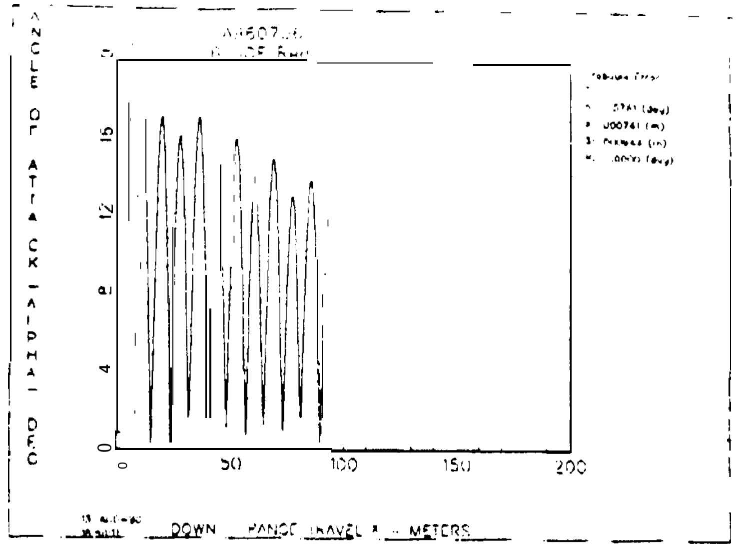


Figure 1a. Shot 36

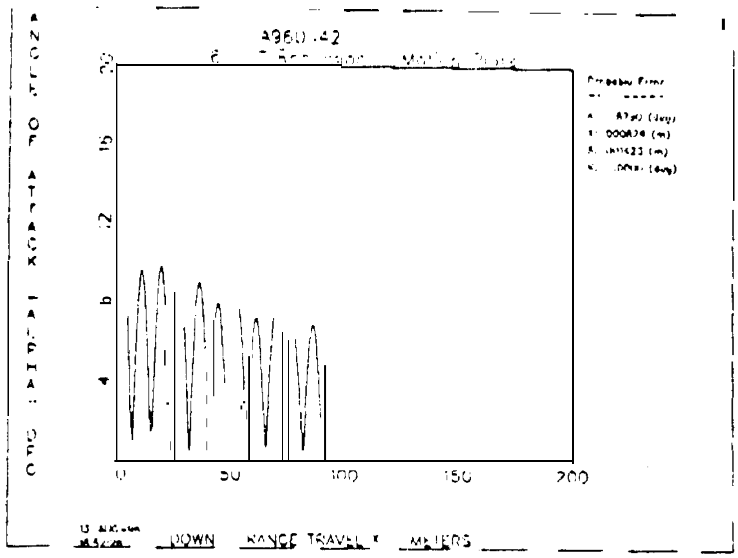


Figure 1c. Shot 42

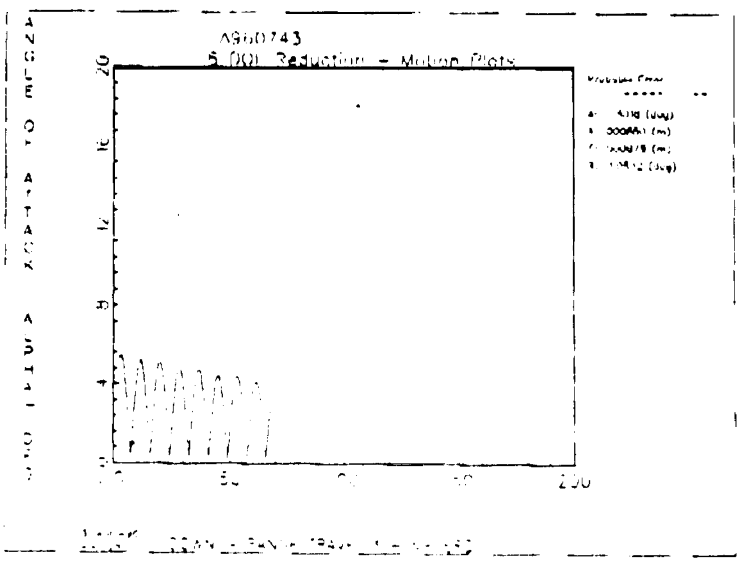


Figure 1d. Shot 43

Microprobe Transonic Performance

Figure 3

Coeff-8 Aug (2) Chart 1

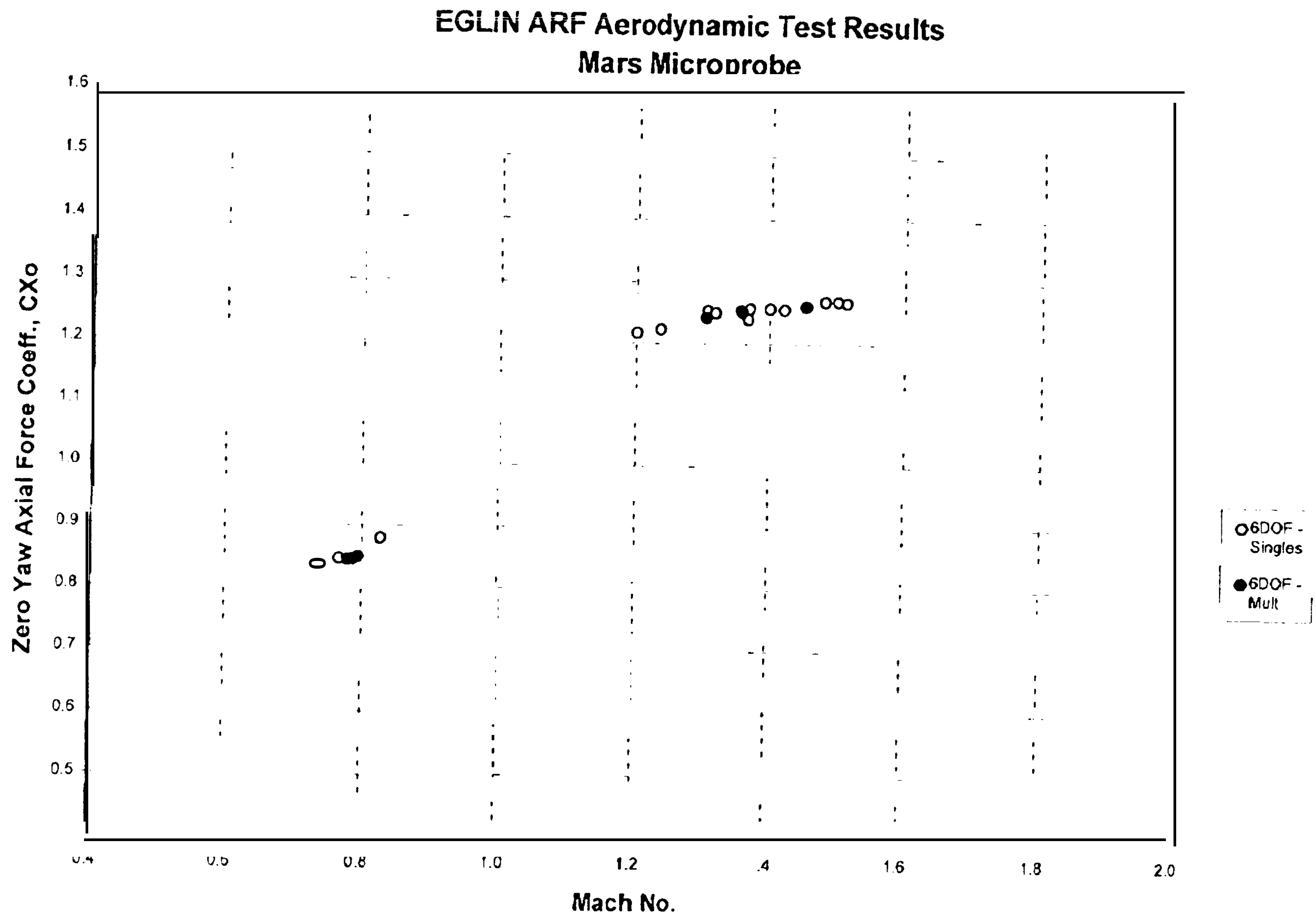


Figure ~~5~~. 4

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Coeff-8 Aug (2) Chart 2

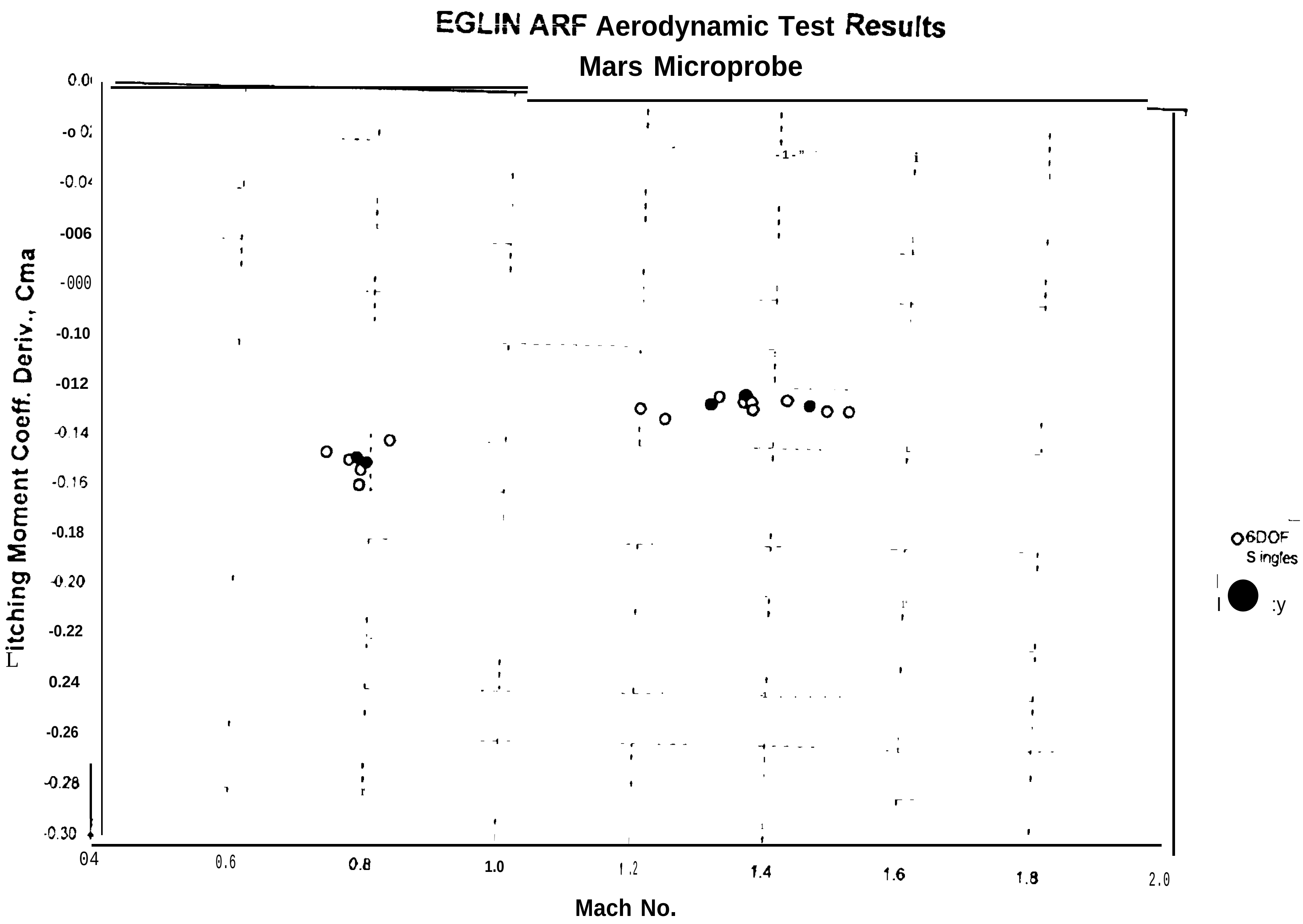

Figure 5

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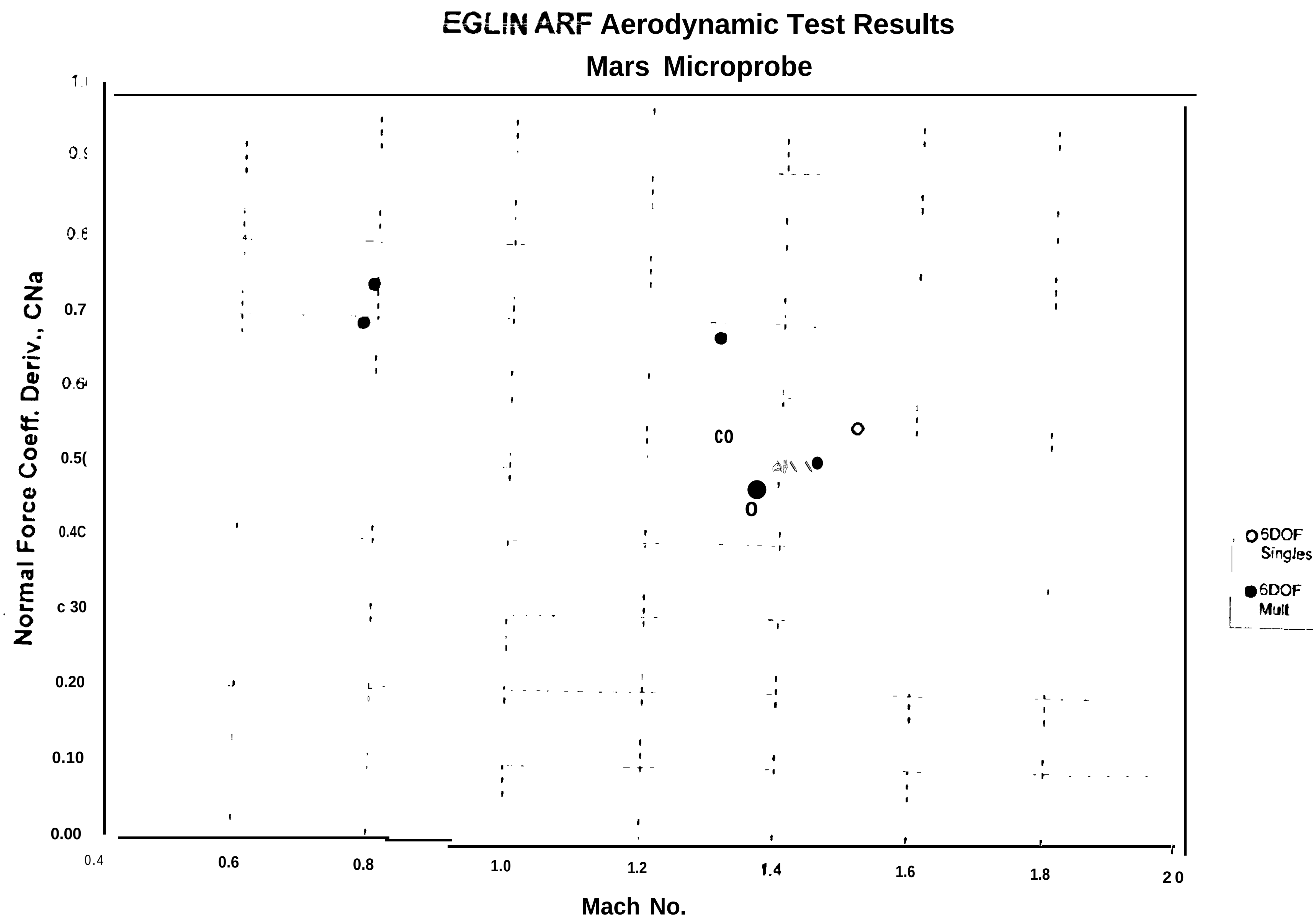
EGLIN ARF Aerodynamic Test Results
Mars Microprobe
Normal Force Coeff. Deriv., CNa
Mach No.
0.00
0.10
0.20
0.7
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
6DOF Singles
6DOF Mult

Figure 6

Coeff-8 Aug (2) Chart 4

EGLIN ARF Aerodynamic Test Results
Mars Microprobe

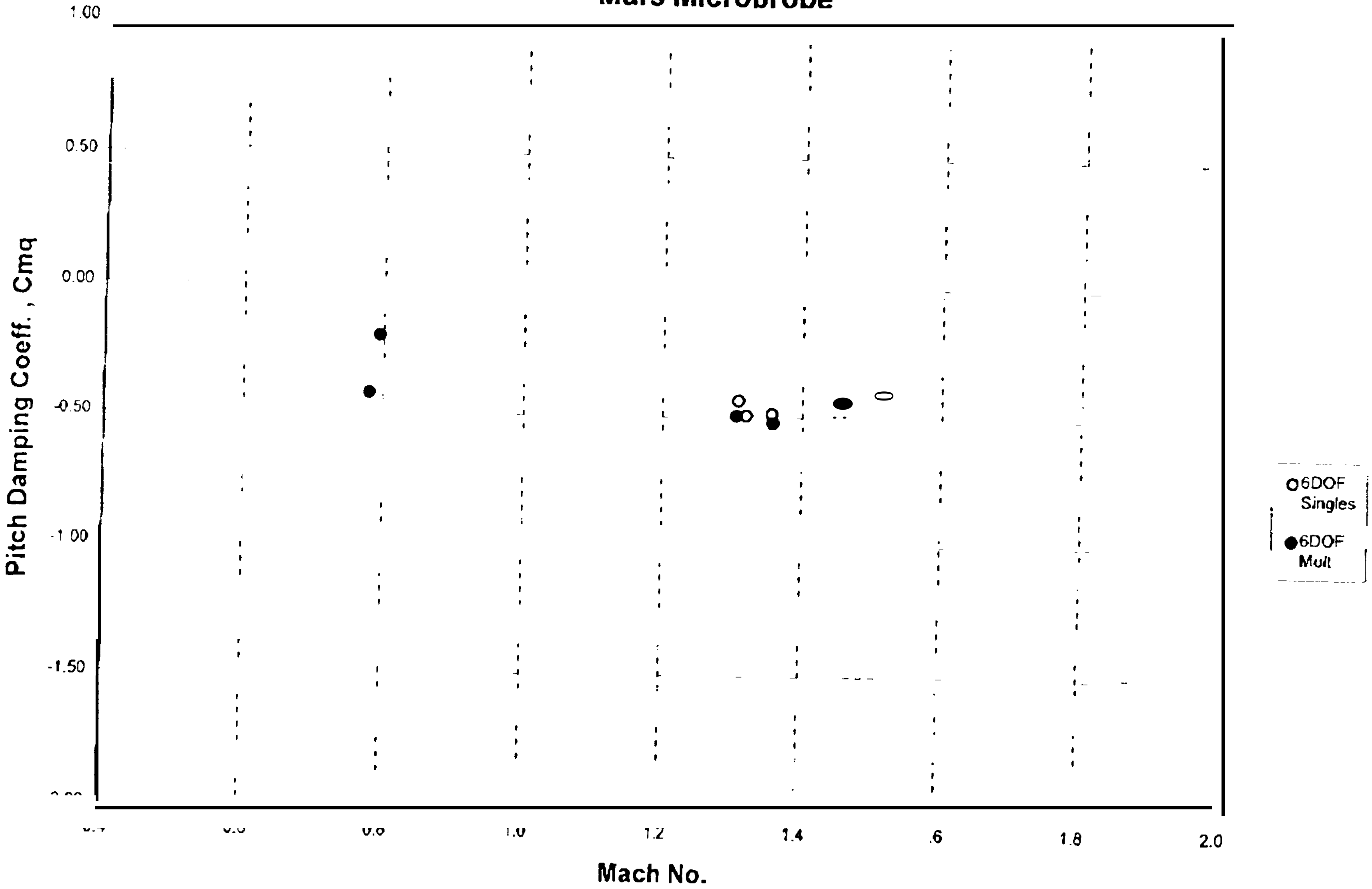

Figure ~~8~~ 7